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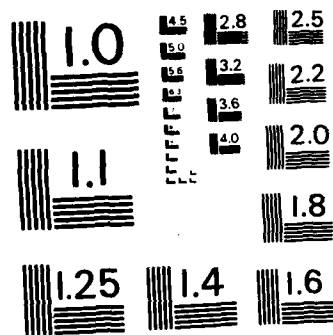
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by

H. Ehbets and H.R. Schwendener



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GUIDING TUNNEL MOLES WITH A LASER THEODOLITE

By: H. Ehbets and H.R. Schwendener

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GUIDING TUNNEL MOLES WITH A LASER THEODOLITE

H. Ehbets and H. R. Schwendener

Since the first HeNe gas laser was introduced in 1960, many attempts have been made to apply this light source to various fields of activity. The visible reference line formed by this bright-red, narrow beam of light can be used in tunnelling, trenching, machine alignment and so on. In the past, alignment work was done with the help of theodolites, levels and alignment telescopes, all of which necessitated an observer behind the instrument to give constant instructions to the working crew ahead. Considerable time and effort can be saved by employing lasers. The narrow beam produced by a laser provides a visible reference at the point of work and eliminates the need for a distant observer, signals and instructions.

Laser devices have made a considerable impact in construction work. They are used to great advantage where pipelines have to be laid, power lines set out, and where machines must follow a stipulated axis with a high degree of reliability. The construction and tunnel lasers used for these purposes are sturdy devices, but usually lacking any precise measuring means for the exact orientation of the laser beam. The desired line is therefore first set out with a conventional surveying instrument and the construction laser is set up and aligned so that the laser beam coincides with the previously defined line. If the basic survey already exists and the control axes of the construction project are straight, the use of construction and tunnelling lasers presents no problems and any supervisor on the construction site will soon master them and appreciate the new technique.

The use of the laser beam to define direction presents more difficulties when the control axis of a project is curved. Of course, it is theoretically possible, by means of a suitable optical system, to direct the laser beam through a series of chords along the projected curve. However, in practice, this method has proved unsuccessful. The laser theodolite has been shown to be a far better solution.

A laser theodolite is a theodolite whose optical line of sight is made visible by means of a laser. Wild Heerbrugg ^{Company} offers a special laser eyepiece, the GLO, which simply interchanges with the standard telescope eyepiece, thus instantly converting the T1, T16, T2 and T3 theodolites, the N3 and NA2 levels, and the Wild optical plummets into laser theodolites, laser levels and laser plummets. The light source of the GLO (Fig. 1) is a 4 MW HeNe laser produced by Hughes Aircraft Company, USA. The laser is connected to the eyepiece by means of a fiber optic which is protected by a flexible plastic-covered metal tube. The fiber is a so-called single-mode fiber, specially developed for the communications industry. It has a diameter of about 100 μm and a very thin core of about 2 μm diameter. This narrow core has a slightly greater refractive index than the outer material. The advantage of this fiber is that the laser light which "flows" through the core keeps its essential characteristics (coherence and fundamental mode).

In order to direct the whole laser beam, or at least as much as possible of the beam, into the core of the fiber, the beam is focussed by means of a short focal length lens to a point of 2 μm diameter at the entry surface of the fiber core. The laser light emerging from the fiber at the eyepiece end (Fig. 2) passes through a lens, is turned through 90 degrees by a beam splitter and is focussed on the front surface of a plane-parallel glass plate (reflection plates), from which about 1 percent of the light is reflected back again towards the eyepiece. The coating on the 45 degree surface of the beam splitter and a coating on the surface of the beam splitter nearest to the eyepiece reduce by a factor 10^{-5} the amount of reflected laser light actually reaching the eye. An observer looking through the eyepiece sees a bright red pinpoint of light that is pleasant and perfectly safe for the human eye. The 45 degree surface of the beam splitter that causes the splitting has a reflective coating consisting of many dielectric layers. It

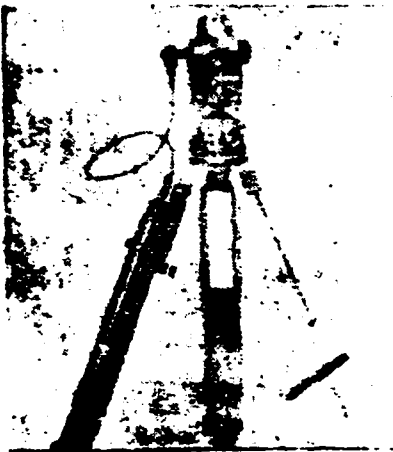


Fig. 1. T2 theodolite with GLO laser eyepiece.

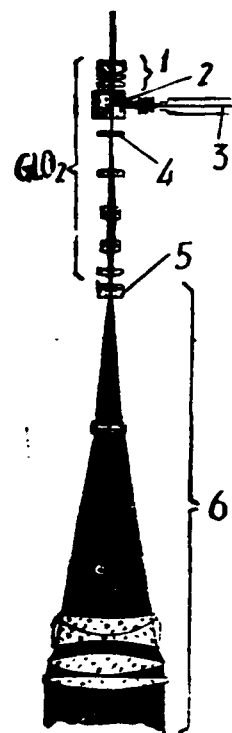


Fig. 2. Path of the laser light:
1 - eyepiece; 2 - beam splitter; 3 - fiber optic; 4 - reflection plate; 5 - reticle; 6 - T2 telescope.

reflects more than 90 percent of the laser light (wave length of $0.633 \mu\text{m}^*$), while simultaneously transmitting normal visible light. The coating on the surface of the beam splitter nearest to the eyepiece functions in the same way. As a result of these coatings, almost all the laser light is directed into the telescope and yet the telescope field of view remains sufficiently bright for observing purposes. The light which leaves the beam splitter and passes through the reflection plate is focussed, by means of an inverting lens system, on the front surface of the reticle plate, i.e. in the plane of the cross hairs. The result is that when the telescope is focussed to a target, the laser light is brought to a focus point on the same target as a small spot of red light. A simple adjustment is provided to adjust the position of the fiber optic at the laser eyepiece end. By this means

* Misprint ($633 \mu\text{m}$) in the original journal [translator's note].

the reflection point seen in the eyepiece can be centered at the intersection of the cross hairs. The axis of the laser beam emerging from the telescope then coincides exactly with the telescope line of sight.

When using normal lasers for alignment, a constant fear is that variations in the direction of the laser beam relative to the laser housing will cause instability of the laser reference line. With the GLO such variations are of no consequence. Because of the GLO's single-mode fiber, a variation in the direction of the beam can only result in some reduction of radiation power, but cannot alter in any way the point and direction of exit of laser light at the eyepiece end of the fiber. This means that with the GLO laser eyepiece, directional instability of the laser beam projected into the fiber has no other effect than fluctuations in the power output from the telescope; there can be no directional change in the axis of the laser beam leaving the telescope. It follows that the GLO is particularly suitable for precise alignment work.

Mapragg pressure shaft

The authors had the opportunity of using the laser theodolite on a practical task, the construction of the Mapragg pressure shaft for the Sarganserland power station in eastern Switzerland. A consortium of companies was entrusted with the construction of the shaft. In plan the tunnel is straight. However, the profile is as follows: the tunnel runs in almost level for 450 m from the power station, then it turns through a vertical curve of 120 m radius, and finally straightens again into an 840 m long shaft with 70 percent gradient leading to the surge tank above. The specifications demanded that the tunnel be bored to within 50 mm of the projected axis. The 4.2 m diameter tunnel was bored by a tunnelling mole from the Demag Company. Stolz AG provided a tunnel laser to guide the machine on the straight stretches. The laser was set up about 400 mm** beneath the tunnel roof. Behind the machine's boring head was a selenium cell device which localized the received laser beam and transformed it into control pulses. This system proved very successful on the straight stretches of tunnel. The effective range of the tunnel laser in conjunction with the selenium cell device was as much as 400 m. As a result, time-consuming relocation of the laser was necessary only at intervals of several weeks.

** Misprint (400 m) in the original journal [translator's note].

Special measures were required for guiding the tunnelling mole through the vertical curve. Due to the size of the machine, there was a free space of only 200 mm to 1000 mm between the roof and the mole through which the boring head was visible. Various installations, including those for earth moving, necessitated limiting to within 1200 mm the distance of the instrument platform from the roof. All these limitations and the 120 m radius of the curve restricted the maximum possible distance between the alignment instrument and the boring head to about 28 m. Since, furthermore, an instrument platform could only be set up behind the driver's cabin, the maximum rate of advance amounted to about 14 m, or a day's work, and then the alignment instrument had to be shifted to a new, forward platform. As it would have been too time-consuming and costly to relocate and set up a tunnel laser without theodolite features every day the decision was made to use a laser theodolite to steer the mole through the vertical curve. It was decided to dispense with the automatic steering control offered by the selenium cell device, as it would have involved continuous resetting of the theodolite telescope. To replace the selenium cell device, an 80 cm-long scale (with cm-graduation) was hung pendulum fashion behind the boring head so that it would always remain vertical irrespective of the angle of climb of the machine. The position of the scale suspension point relative to the actual floor of the tunnel could be derived from the known dimensions of the machine. Using a coordinate system in a vertical plane, the horizontal distance and the difference in height between the scale suspension point and the start of the curve were precomputed for intervals of 400 mm along the curve.

As the position and height of the laser theodolite and the vertical angle setting of the telescope could not be known beforehand, the final alignment information - that is the heights (or readings) at which the laser should strike the scale according to the distance advanced - could not be precomputed. Only after the laser theodolite had been set up on a new instrument platform could the final alignment data be calculated (Fig. 3).

For the 72 m-long vertical curve the laser theodolite had to be moved forward only six times. The procedure for each move was as follows;



Fig. 3. Instrument platform with laser theodolite and battery.

The new instrument platform was set up under the roof of the tunnel.

A traverse target in a theodolite tribrach was set on the new platform and lined in by theodolite from the rear platform. The traverse target was then replaced in the tribrach by the laser theodolite (forced centering).

After measuring the distance and vertical angle, the position and height of the laser theodolite at the new platform were calculated.

After sighting to the target on the rear platform, the telescope was set to the forward direction of the tunnel by means of the horizontal circle.

The maximum telescope inclination possible under the restricted sighting conditions was set and the vertical angle read.

The required positions of the laser dot on the hanging scale - for the advancing mole - were computed and tabulated.

The next most important step was giving the site supervisor the necessary explanations and instructions. From his cabin the driver was easily able to see the scale with the bright laser dot and guided the machine accordingly. Regular tape measurements determined the rate of advance.

In solving such problems, economic aspects are often more important than construction tolerances. In the above case, the important aspect was the answer to the question: which variant keeps the downtime of the mole to a minimum while surveying is in progress? The solution with the laser theodolite reduced to two to three hours the work stoppage between setting up the new instrument platform and recommencing cutting. With a normal tunnel laser, twice the downtime would have been necessary for each repositioning.

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